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Volume 11 July, 1925 *Number 7*

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Some Recent Developments in Automotive Engine Lubrication

PUBLISHED MONTHLY BY
THE TEXAS COMPANY, U.S.A.
TEXACO PETROLEUM PRODUCTS

TEXACO GASOLINE — PURE, CLEAN, VOLATILE

TO THE READER

IT is our pleasure this month to give you an entire issue devoted to the Automotive Engine. We feel that the ensuing article will be of interest to the layman and "professional."

The man who drives his own car and who has given only passing attention to fuel and lubricants will find much of value and possibly some surprisingly new ideas which will suggest a way towards more economical operation.

The advanced student of automotive functions will, we are sure, welcome this article, because its material is drawn from such wide and authoritative sources. As a matter of fact we have never to our knowledge encountered so much information "boiled down" in the compass of so few pages. We can say this with due sincerity, for all credit belongs to those scientists on whose findings we have drawn so freely.

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Texaco Petroleum Products
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TEXACO MOTOR OIL — CLEAN, CLEAR, GOLDEN

LUBRICATION

A Technical Publication Devoted to the Selection and Use of Lubricants

Published Monthly by

The Texas Company, 17 Battery Place, New York City

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Vol. XI July, 1925 No. 7

Change of Address: In reporting change of address kindly give both old and new addresses.

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Some Recent Developments in Automotive Engine Lubrication

THE matter of automotive engine lubrication has always been regarded as a most important factor to the automobile owner. In consequence intensive studies have been periodically made from a research point of view. Many of the discussions evolved have been hypothetical, others in turn have been subject to revision in accordance with extended developments. On the whole, until but recently, the science of automotive engine lubrication has been vague and more or less of a haphazard proposition. But, of course, this could not continue thusly. The necessity for more reliability in engine operation, the desire for increased mileage, and conservation of petroleum resources, etc., demanded otherwise.

Hence the era of the scientist and the dynamometer laboratory. Hence the expenditure of vast sums to prove or disprove conventional theories; to improve the running of *the average automotive engine under average operating conditions;* all to insure better economies and lower maintenance costs.

In this era of research the Society of Automotive Engineers, the Bureau of Standards, the Automotive Engine Builders and the Petroleum Industry have been the outstanding leaders. Their research personnels comprise the cream of scientific talent, their laboratories have been spared no expense in development. In consequence the results of their investigations have been revolutionary, and been substantiated in actual road test operations, thus proving to be of immeasurable interest and value to the motor car or truck owner and operator.

Most recently have these investigations leaned towards engine starting, engine cylinder lubrication, oil flow in complete bearings, the importance of dilution, the prevalence of water on cylinder walls and in the crankcase and the matter of low carbon in the lubricating oil.

ENGINE STARTING

Of the above mentioned researches, the matter of engine starting is perhaps of the most pertinent interest to every motor car driver, especially in winter. The engine must be started before fuel combustion, lubrication, or any other phase of its operation can be observed.

Eisinger*, in his recent research on the subject of Engine Starting, ran his tests at the Bureau of Standards with a view to determining just what factors influenced the time required for starting, the problem being to provide the engine cylinders with sufficient fuel vapor to form an explosive mixture, and a spark

*Engine starting tests by John O. Eisinger, Automotive Power Plants Section, Bureau of Standards. This work was instigated by The Cooperative Fuel Research Committee formed by representatives from The Society of Automotive Engineers, The Automobile Chamber of Commerce, The American Petroleum Institute and the Bureau of Standards.

NOTE: Figures 1, 2, 3, 4, 5, 6, 7, 8, 11 and 12 are reproduced by courtesy of J. O. Eisinger and The Society of Automotive Engineers.

to bring about ignition or firing. Extensive research was carried out, using an engine-dynamometer hook-up. (See layout arrangement Fig. 1.) The general procedure was to drive the engine by the dynamometer until operating conditions were constant, then the fuel was turned on and the time required for starting and the fuel consumption noted. Provision was made for measuring the fuel consumption, changing the jet size, jet location, rate of fuel flow, choke and throttle opening, and taking the necessary water and air temperatures. The results obtained are shown by a number of curves, certain of which are reproduced herewith.

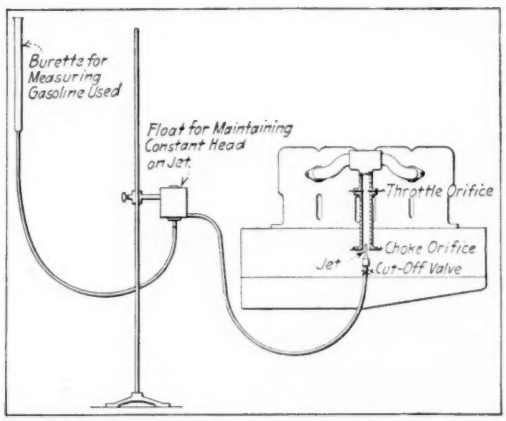


Fig. 1.—Engine-Dynamometer hook-up as used for engine starting tests carried out at the Bureau of Standards. In this work the carburetor was replaced by a single jet which was located in a vertical section of pipe. This was of the same inside diameter as the intake manifold, being connected with the latter.

In effect these tests developed that some of the factors which apparently influence engine starting are the fuel-air ratio, the jet size, jet location, spark advance, volatility of the fuel, amount of throttling, amount of choking, temperature of entering air, and the jacket water temperature.

CYLINDER AND BEARING LUBRICATION

With a more intimate knowledge available of the factors which will tend to affect the starting of an automotive engine we are then in a position to study the matter of cylinder and bearing lubrication. A. Ludlow Clayden* has investigated this problem in exhaustive detail from the viewpoint of observing the effect of higher cylinder wall temperatures upon dilution. D. P. Barnard* has in turn investigated the rate of oil flow through complete journal bearings. Eisinger, and Frank Jardine have also touched on the matter of cylinder lubrication, the latter in particular having brought out some extremely pertinent data in an article in Automotive Industries,** relating to scuffed or scored pistons and rusted cylinders due to cold jackets, lack of oil when starting, and the presence of water of condensation on the cylinder walls after shutting down.

Initial Cylinder Lubrication

The all important point after starting an engine is to obtain the delivery of sufficient lubricating oil to the cylinders to insure the requisite lubricating film. Jardine has made the alarming discovery that this may frequently be impossible of attainment in the modern engine, for a matter of several minutes after starting. During this period the cylinders and pistons may run dry, giving rise to scuffing or scoring of piston surfaces.

In this connection further details of his investigations will be of decided interest. Especially did this work apply to piston and cylinder oiling by means of pressure or force feed lubrication. He developed that—"Engines which have close big end bearing clearances frequently run for five or more minutes before oil from the pressure feed system reaches the cylinder walls—under ordinary room temperatures. At lower temperatures the period of dry running is lengthened. This often results in scored or "scuffed" pistons. Increasing the clearance or providing suitable grooves obviates this difficulty."—furnishing the apparently necessary oil to make a film. At higher temperatures but little oil is necessary to maintain this film especially as the possibility of condensation is remote. At lower temperatures, however, Jardine has developed that rust will be formed very rapidly, due to the presence of water of condensation which washes off the lubricating film. The hotter the cylinder walls, within reasonable limits, the less will be the amount of condensation and hence, as expected, the more effective will be the lubricating film as a rust preventative. Rust, has been proven to be often a factor in the scoring or scuffing of pistons. To eliminate rust and insure better cylinder lubrication, the essential problem is to eliminate condensation and water. Jardine states that—"scuffing was eliminated by throwing more oil into the cylinders"—just as it was also eliminated by—"simply raising the cooling water temperature from 35 to 125 degrees Fahr."—In fact—"no matter how severe the scuffing might be it disappeared entirely if hot water were circulated through the jackets."

These tests are of such interest in certain details, especially as to the occurrence of water and its detrimental effects, that certain phases

*In a paper presented at the 1925 Summer Meeting, Society of Automotive Engineers.

**July 31, 1924.

of the research work are quoted intact. For example:

"When the cylinder heads were removed from engines which had been operated in the cold room at temperatures around zero and below it was noticed that a coating of rust had formed on the cylinder walls even though they were covered with a film of oil. This rusty coating formed with almost incredible speed, inside of 10 or 15 minutes, and would absorb what oil was present leaving a dry, red surface on the cylinder walls. The rusting was not entirely confined to cold room engines but occasionally was to be seen in a less aggravated form in engines which had been run on the block with cold water circulating through them."

Water in Crankcase Oil

"It was observed also that when the oil pan was removed from engines which had been operated on the block under cold water conditions, large drops of water frequently would be found clinging to the crankshaft and the oil which was on the pistons when they were removed was of a dirty yellow color, as though it were loaded with water. This was never the case when hot water was circulated through the system.

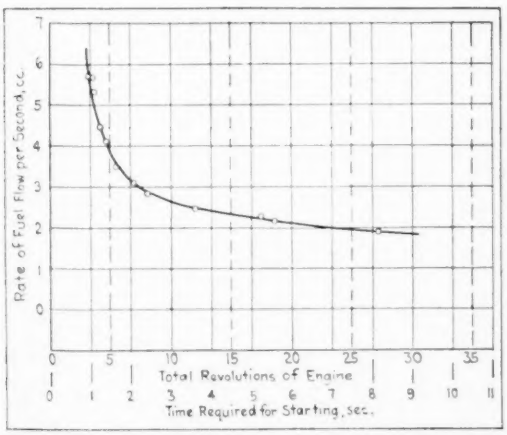


Fig. 2.—Curve showing the relation between fuel flow and the time required for starting. Due to the fact that the air flow was maintained constant, the ordinates are proportional to the fuel-air ratio. Within certain limits, it can be seen that the richness of the mixture determines the number of revolutions that will be necessary before an explosion occurs.

"These facts led to the supposition that the basic cause of all the trouble was condensation on the cold cylinder walls of water which ruined the lubricating properties of the oil film, and, under certain conditions, caused the cylinder walls to rust, thus increasing the scuffing. Exhaustive tests proved this supposition to be correct. The oil which was on the pistons after they had been run through the five start test* described above was found to contain 25 per cent of water."

Water Causes Rust in Cold Engine

"In connection with the rust formation a number of very interesting experiments were tried. In one case the oil pan was filled with water instead of oil, a sufficient quantity being used so that the rods dipped deeply and the cylinder walls were kept well splashed. Hot water (180 deg. Fahr.) was circulated through the jackets and the engine was driven with the dynamometer for the regular five starts and then allowed to stand over night. The next morning the cylinder head was removed and the cylinders were found to be clean and bright. The hot walls had dried off as soon as the engine was stopped."

"The same experiment was repeated except that cold water was circulated through the jackets. When the second start was attempted after the first 30 minute idle period, the engine was difficult to turn over and squeaked slightly. After the second run the cylinder head was removed immediately and every piston was found rusted into its cylinder so tight that it had to be driven out with a hammer. Cylinder walls were covered with rust and were scored throughout their length. Pistons, of course, were ruined utterly. In this case the water had not been driven off the cylinder walls when the engine was stopped, but had remained to cause the rusting."

Under average operation in cold weather the occurrence of condensation and the presence of water on cylinder walls and in the crankcase oil is very prevalent. To prevent it, the evident recourse is to keep the engine and crankcase from cooling down abnormally when standing. This can be partially accomplished by suitable jacketing of the crankcase, covering of the radiator, and storing in a warm garage. Due to the fact, however, that condensation may occur in spite of these precautions, or through failure to observe any one of them completely, provision should also be made to insure the same abundant supply of oil to cylinders of every force feed lubricated engine, on starting, as is obtained in a splash lubricated engine. This can be attained as Mac Coull suggested before the American Petroleum Institute by eliminating the by-pass valve and using oils of lower viscosity.

All this will also prevent dilution. We must remember, however, that heating the oil to the necessary degree may effect a greater reduction in viscosity than were dilution allowed to occur. Such viscosity reductions, however, are not as serious as one might believe off hand, for tests

*This involved five 5-minute runs, separated by 30-minute shutdown periods.

have indicated that there will normally be sufficient body left to give the requisite lubricating film to the bearings. At the same time under jacketed crankcase conditions cylinder lubrication will probably be improved due to the normally higher viscosity of the oil.

RATE OF OIL FLOW IN BEARINGS

The fact that bearing lubrication is intimately connected with cylinder lubrication, in turn, renders the investigations of Barnard, as mentioned above, of interest. The approximate nature and thickness of the lubricating film is of decided importance. At best our knowledge of the extent to which lubrication is taking place between engine bearing surfaces is meagre. In fact, only over the long run, can the ability of any oil to maintain the requisite lubricating film be determined. **On the other hand the more highly refined the product, and the lower its tendency to produce hard, adhering carbon,** as will be brought out later, **the more reliance can be placed in it.**

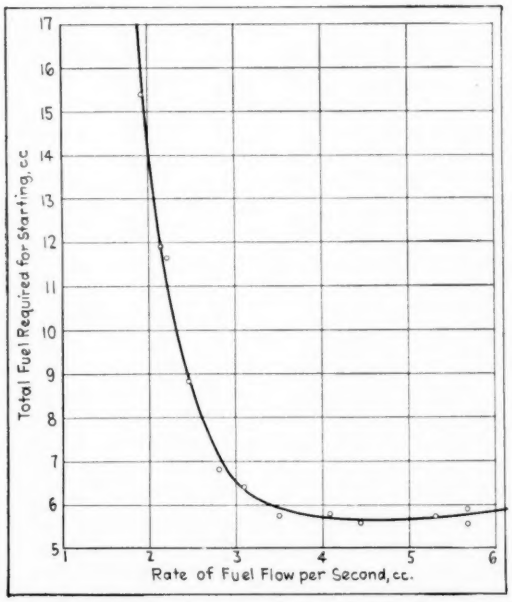


Fig. 3.—This curve which shows the total amount of fuel used in starting plotted against the rate of flow, indicates that the volume required is least for comparatively rich mixtures. In determining this data after running a sufficient length of time (by the dynamometer) to render engine conditions constant, the fuel was turned on and the time taken for an audible explosion to occur.

This research was carried out with a view to developing certain general laws governing the rate of flow of oil through complete journal bearings. In the case of high duty bearings such as are employed in automobile engines the probable rate of oil flow through bearing clearances is of course an important factor not only in bearing design but also in performance. Essentially will we be confronted with the problem of removal of frictional heat, for all such bearing surfaces are relatively small in regard to the amounts of metallic surface available for dissipation of such heat, too, the chances for radiation or removal of heat by contact with the air is practically negligible.

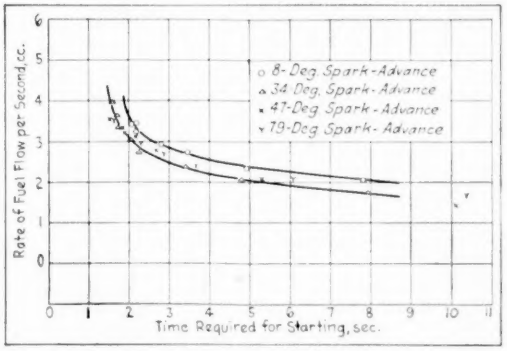


Fig. 4.—(Fig. 5 Engine Starting tests.) Curves to show the effects of spark advance upon starting. These tests indicated very definitely that an advance of approximately 35 degrees gave a much shorter starting time than one of about 10 degrees, and a somewhat shorter time than one of approximately 50 or 80 degrees. Retarding the spark beyond top-center gave even poorer results.

But in order for a lubricating film to remove frictional heat effectively it must naturally penetrate throughout the bearing clearance space. Barnard has developed by means of his motion picture study of bearing lubrication, that this may not always be possible. In his opinion a plain bearing can be regarded as a pump in which during the flow of a viscous lubricant through a passage of varying area a pressure is developed sufficient to sustain the imposed load.—"Oil flow in the direction of the axis of such a bearing is due to two causes:

1. "Oil film pressure developed to support the bearing load."
2. "Oil feed pressure."

"The item of primary interest is the oil flow due to the first of these causes, in other words, the important thing is efficiency of the bearing as a pump. Therefore it is necessary that the relation of oil flow to pressure due to motion in the oil film be thoroughly studied. On the other hand it is a recognized fact that oil pressure is an important factor in bearing performance."

Oil Flow Due to Pressure in the Film

While the clearance space in an efficiently lubricated bearing should theoretically be completely filled with oil, the revolving journal carrying a certain amount of the latter around with it, where loads are carried by the journal the lubricating film will tend to be displaced, considerable pressure being developed in the

restricted portions of the clearance space. As Barnard states:—"These pressures result from the force required to drag the oil through the wedge shaped clearance space, and vary from point to point throughout the film. The resultant of all such pressures acting on the surface of the bearing must be equal to the imposed bearing (or journal) load and therefore may be regarded as a function of that load."

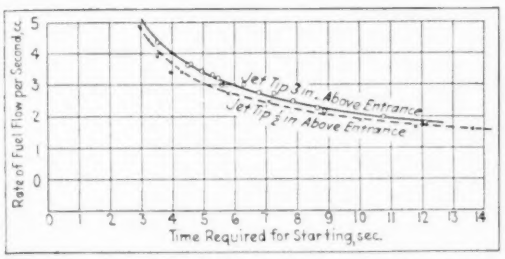


Fig. 5.—(Fig. 8, Engine Starting tests.) Curves showing relation of jet location on time required for starting. It can be noted that better results were obtained with the jet outlet half an inch above the entrance than with it about 3 inches above.

"As the motion of the journal tends to carry oil in the direction of rotation only, end leakage must be due solely to the pressure in the film."

The usual amount of reduction in viscosity due to dilution, in the average engine to-day will, of course, tend to promote the pumping of oil by journals in their rotation, inasmuch as lighter fluids will lend themselves to more ready handling, if it can be called such, but only under lower speeds. The higher the rubbing speeds the lower will be the pumping efficiency of the bearing. Furthermore, increase in the rubbing speed between a journal and bearing causes an increase in frictional heat. As a result a diluted engine oil, under higher speeds and normal operating temperatures must possess very high lubricating ability and be as free as possible from carbon or other foreign matter if it is to furnish a suitable film to protect the bearings. **Only can this be obtained by the most careful refinement, and the rendering of the original oil as pure as possible.**

Unless the oil is given every attention in its refinement there will be considerable possibility of it being broken down in service especially where the frictional heat developed in the bearing is not being adequately carried away by the oil itself. The ideal in automotive bearing construction is to plan for practically the entire removal of frictional heat by the oil, thereby preventing this heat from reaching either the bearing surface or journal. But this ideal is not practicably obtainable. Therefore the oil must be of such a character as to—

1. Be capable of maintaining the requisite lubricating film.

2. Resist the breaking down effects of heat as far as possible.

3. And develop as little hard carbon as possible if subjected to continued service under overheated conditions.

Carbon in an engine combustion chamber, on valves, piston heads, on spark plugs or in ring grooves, etc., is a detriment from the viewpoint of ultimate power developed. In bearing clearance spaces, however, it may in addition result in mechanical failures due to an impairment of circulation of the lubricant by the clogging of grooves or oil ducts. It must, therefore, be guarded against with the utmost care.

Another interesting and extremely important point involving carbon is that in the free state it has an apparent tendency to promote or aid oxidation just as does other foreign matter such as particles of brass, copper, iron, or dust and dirt. Of course oxidation of lubricating oil is not as serious a matter in an automotive engine as in the steam turbine. On the other hand it is the forerunner of emulsification and the development of insoluble sludge, especially where the oil is agitated in heated condition with any water which may have gained entry into the crankcase.

We must remember that oils, whatever their purity, will be subjected to more or less oxidation where agitated with an appreciable

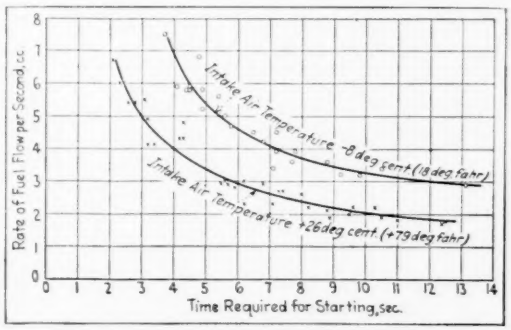

Rate of Fuel Flow per Second, cc.
Intake Air Temperature -8 deg. cent (18 deg. fahr.)
Intake Air Temperature +26 deg. cent (+79 deg. fahr.)
Time Required for Starting, sec.

Fig. 6.—(Fig. 11, Engine Starting tests.) Curves showing the effects of differences in vaporization which are brought about by differences in air temperatures. This marked effect will be no surprise to those accustomed to drive in colder climates.

amount of water under continued high temperatures and in the presence of air. On the other hand the more highly refined the oil, or in other words, the greater its purity, the more remote will be the possibility of oxidation occurring to an abnormal extent.

In brief, research indicates that there are certain component hydro-carbon fractions which oxidize more readily than others. These

can be removed in the process of refining, as experimentation and practice have demonstrated, to the evident improvement of the resultant lubricating oil. **Color is a decided indication of the purity of an oil, and other things being equal the clearer, lighter products are better adapted to the exacting conditions which exist in the average automotive engine.** Too, the lighter the oil the lower will be its free carbon content, for color after all, is largely due to very finely divided carbonaceous matter which is held in suspension. To prove this statement we have but to compare the opaque steam cylinder oils with their correspondingly high carbon content, with the pale transparent motor oils in which free carbon will run in the neighborhood of .01 to .03 of one per cent.

According to certain authorities if emulsification is prevented, the tendency towards sludging will be greatly decreased, assuming, of course, that a certain amount of water must always be contended with in practically every crankcase. It would therefore seem logical to attempt to eliminate the so-called foreign matter catalyzers including free carbon, as mentioned above, which promote oxidation and ultimately give rise to sludging. Emulsification is certainly not as detrimental as sludging. Emulsions alone are not as objectionable as insoluble sludges which may tend to clog oil passages, congest the lubricating system and generally reduce the ability of the oil to give continued and effective lubrication.

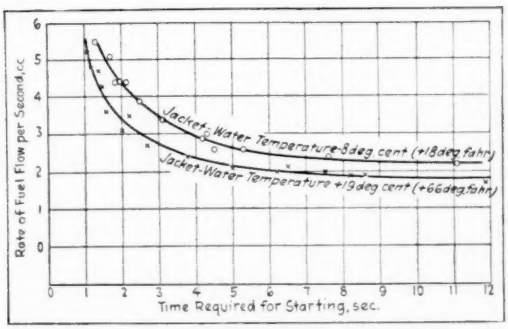

Rate of Fuel Flow per Second, cc
Time Required for Starting, sec.
Jacket-Water Temperature 8deg cent (+18deg fahr)
Jacket-Water Temperature +19deg cent (+66deg fahr)

Fig. 7.—(Fig. 12, Engine Starting tests.) The effect which the temperature of the cooling medium surrounding the cylinders has on the amount of fuel required for starting is shown by these curves. The problem of starting in cold weather does not consist of merely getting fuel into the engine, for the quantities of the latter necessary for starting may differ materially for different jacket water temperatures.

THE RELATION OF CYLINDER TEMPERATURES TO DILUTION

And then, there is the matter of dilution; to reduce the occurrence of dilution has been one of the ideals of many automotive research engineers. Dilution in its reduction, however, automatically involves certain possible difficulties as clearly brought out by A. Ludlow Clayden* in his paper on "Cylinder and Engine Lubrication."

As a matter of introduction it will be interesting to review this subject of dilution as it affects the present day car owners.

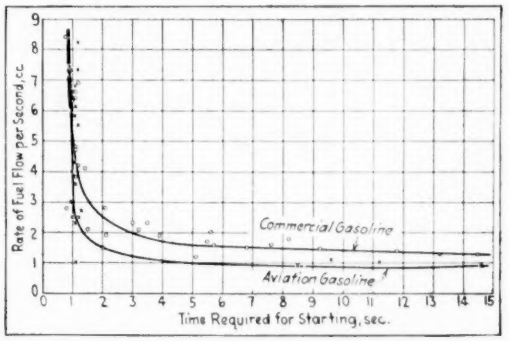


Fig. 8.—(Fig. 16, Engine Starting tests.) That vaporization results from throttling and choking, is indicated by the above curves. Essentially they indicate the effect of fuel volatility on starting.

Dilution has heretofore been more or less regarded as the "ogre" of efficient automobile lubrication. Generally, it has been overstressed. The fact that an engine oil under ordinary conditions of crankcase temperature and operation becomes rapidly reduced in body or viscosity by the apparent entry or admixture of unburned fuel appears to be a serious matter. If theoretically effective lubrication of our engine calls for a 500-second viscosity oil and the oil in our crankcase has been reduced to the neighborhood of 200 seconds viscosity after a few hours of operating, the first thought is that something may be wrong. Furthermore the fact that lubricants of different viscosities are recommended for summer and winter service is no actual protection against dilution under engine conditions as they exist to-day. However rigidly the motorist may adhere to the recommendations, dilution will practically always occur in his crankcase. This has been realized by the automobile manufacturer and oil marketer and their recommendations for the lubrication of such engines have been made accordingly. For example, the recommendation of a 300 seconds viscosity oil to-day does not indicate that the absolute maintenance of 300 seconds viscosity may be necessary. It simply means that in practical running a new oil of 300 seconds is the best oil, all factors of operation and construction being considered.

As it occurs to-day dilution is due to condensation or deposition of a certain amount of unburned fuel on the cylinder walls, which

*Presented at the 1925 Summer Meeting of The Society of Automotive Engineers.

eventually reaches the crankcase, due to the continued interchange of freshly sprayed oil with the oil film on the cylinder walls.

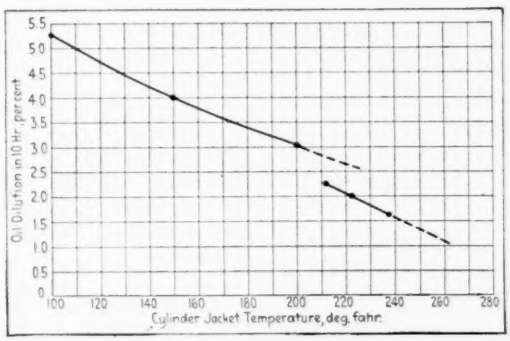
Dilution is generally regarded as being intimately influenced by the engine temperature. In other words, the temperature of the cylinder must be sufficiently high to insure complete vaporization and burning of this fuel. Otherwise more or less of the heavy ends or fractions of low volatility will remain unvaporized.

In order to burn gasoline or kerosene effectively in an internal combustion engine, it must be atomized and mixed with a certain amount of air. To attain efficient vaporization this mixture of fuel and air must be heated in order to insure the best results. The direct consequence of exceedingly rich mixtures will be dilution of the lubricating oil in the crankcase, under engine temperatures as they exist to-day. Of course, when the engine is operated under average conditions of atmospheric temperature or after it has come up to its own normal temperature of operation there will be little or no difficulty experienced in vaporizing the average grades of gasoline. Under relatively cold engine conditions, however, the amount of gasoline which will be vaporized will normally be decidedly lower. There are two ways by which this difficulty can be overcome to a certain extent, i. e.:

By the use of gasoline of relatively higher volatility, or by "priming" or "choking" of the carburetor.

Priming is the addition of an extra amount of gasoline to the cylinders through the pet cocks or priming pump. Choking constitutes the manipulation of the carburetor in order to increase the richness of the mixture, or obtain approximately the requisite percentage of fuel in the form of gas by reducing the amount of air delivered to the carburetor on starting. Carburetors are normally adjusted when hot in order to obtain good fuel economy, and to decrease dilution; hence a certain amount of control by means of the choke is made necessary in order to meet cold weather conditions as mentioned above.

Priming and choking, however, while they facilitate starting a cold engine are also conducive to increased dilution inasmuch as under such conditions less of the gasoline will vaporize than when operating under normal temperatures. As a result, considerably more of the higher boiling point fractions will remain in liquid state, to leak past the piston rings and either wash the film of lubricating oil from the cylinder walls or become so incorporated with this film that consequent reduction in viscosity will result. The ultimate consequence of either of these occurrences will be dilution due to entry of the fuel into the oil film on the walls or into the crankcase. Due to the fact that the cylinder walls will always be insufficiently lubricated at such a time after the use of the choke, the engine should be operated at moderate speeds until the film of lubricant is renewed on all surfaces where any washing action has taken place.



Courtesy of A. L. Clayden and The Society of Automotive Engineers.

Fig. 9.—Curves showing relation between dilution and cylinder jacket temperatures. The upper is the water cooling curve, the lower being the steam cooling curve.

It is evident that during cold weather operation with average fuels we will therefore experience more or less dilution in the present day engine, due to the presence of unvaporized fractions of the fuel in the system. The use of more volatile gasoline, of course, would obviate this condition to a certain extent. The fact must not be overlooked, however, that dilution will occur with any motor fuel even where so called high test aviation gasolines are used. **The higher the volatility, however, the less will be the necessity for using the choke in cold weather operation.**

Both priming and choking must be carefully carried out. Especially in the use of the choke will there be the possibility of considerable dilution occurring. If used excessively for any length of time naturally a comparatively uniform flow of very rich mixture will occur. The correct way is to alternately work the choke slowly back and forth until sufficient explosions have taken place to insure continued operation. It should then be pushed in gradually and the engine idled until sufficiently warmed up. During the process of warming up it is well to adjust the spark and throttle levers as nearly as possible to a point where the engine will run evenly and fire on all cylinders. Where cars are equipped with a primer, in very cold weather the priming charge should be shot into the manifold while turning the engine over with the starter. This will insure

getting the charge into the compression chamber.

In connection with this matter of "choking," it is interesting to note certain of the data developed by J. O. Eisinger, in his work on Engine Starting tests. It is his opinion that "Due consideration should be given to the fact that the lubricant upon the cylinder walls will be diluted to far greater extent by admitting fuel for several revolutions without an explosion than by admitting a like total amount in a single revolution in which an explosion is obtained. On a cold winter morning when one expects that each revolution of the starter will be its last,—the fact that the rich mixture reduces the number of revolutions required is far more important than the other advantages mentioned."

The question of using higher volatility grades of gasoline so frequently arises that it is well to discuss this subject briefly. To-day gasolines contain considerably more of the lower volatility hydrocarbon fractions than formerly, due primarily to the efforts of production to meet the quantity demanded by the public. Gasolines produced under modern refinery processes have a higher final boiling point than those which were formerly manufactured. As a result they are heavier in comparison and require higher temperatures for vaporization, notwithstanding the fact that they are capable of developing more power.

Dilution will also vary to a certain extent with the design and mechanical condition of the engine, as well as with the volatility of the fuel. Where an engine is designed especially to burn a certain grade of gasoline the possibility of dilution occurring will be decreased. This is also true where provision is made to keep the oil temperatures relatively high as is brought out in discussion of recent published investigations. While but little has been done in installing provisions for heating the lubricating oil in the crankcase of the average car to-day, in practically every other way effort has been made to design engines so that the least amount of dilution will occur. As a result a tractor engine designed to burn kerosene should show no more dilution than an automobile engine designed for gasoline of considerably higher volatility. The increased temperature of operation in the event of heavy service will decrease the rate of dilution to a certain extent by virtue of the fact that the so-called heavy ends of the fuel will be more completely vaporized and burned. As well carburetor adjustment will play an important part.

It is decidedly interesting to note the accompanying curve, which shows the rapid drop in viscosity, due to dilution. As can be seen it does not require very much diluent mixed with the motor oil to reduce the viscosity or thin down the oil sufficiently to perhaps render it less effective as a compression seal. It has often been determined that dilution occurs very rapidly over the first few hours of operation after the lubricant has been renewed in the crankcase.

There has been an extensive discussion as to just how important this matter of dilution really is and just what harmful effects may result from its occurrence. The dangers therefrom have, of course, been exaggerated, as is always the case. Up to this time any efforts

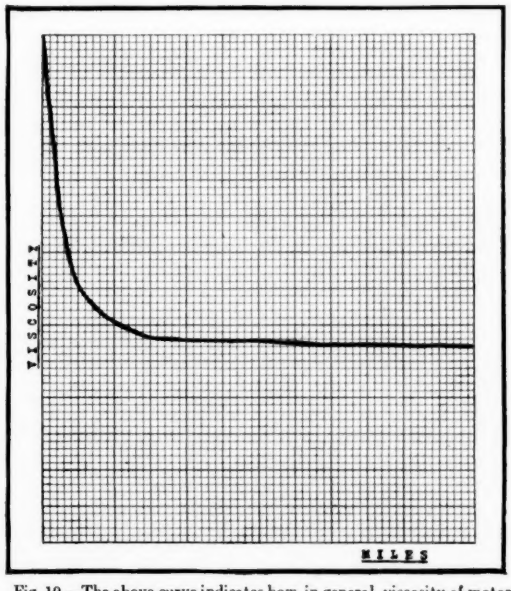


Fig. 10.—The above curve indicates how, in general, viscosity of motor oils decreases with mileage. Definite figures as to how rapidly viscosity reduction will take place (owing to dilution) or as to just what the ultimate viscosity will be, will vary in different instances. It has also been found that the curve will be relatively smooth in some cases while in others it will be undulated to a certain extent. The exact form of such a curve will depend upon the make of the car, its age, the efficiency of the engine, the amount of make-up oil added, and more particularly upon the ability of the driver to handle his car properly.

which have been made to overcome dilution have provided for elimination after occurrence. Usually these have involved heating of the oil. This is not really desirable as it inevitably gives rise to oxidation. Where oil dilution exists it is logical to expect that more power will be developed at the crank shaft, due to the decrease in internal friction in the lubricant, provided it is not diluted to such an extent as to allow metal to metal contact.

The presence of water, sludge, emulsion, grit and dirt all tend quite as much to promote inefficient lubrication. In fact an excess of sludge, which might clog oil ducts or render the pump inoperative would certainly cause more

direct damage than a mere reduction in viscosity of the lubricant.

It will appear that from a lubricating point of view there is little probability of bearings being actually burned out, because the viscosity of the lubricant has been reduced to the extent that it would be under average cases of crankcase dilution. Any number of instances are on record where motor trucks have experienced dilution to the extent that their crankcase oil was decreased to less than one-fifth of the original viscosity. Yet they operated effectively and on examination their engine bearings showed practically no ill effects. When trouble is experienced it will usually be due to abnormal operating conditions.

Dilution Proved Subject to Limitations

Clayden's investigations proving the apparent relationship between cylinder temperatures and dilution show:—

"That there is a sharp reduction in dilution as the boiling temperature is reached and that the amount of dilution at temperatures of 212° or over is much less than would have been anticipated from the results obtained at temperatures below 212°."—He also—"points out that high cylinder temperatures reduce dilution to a negligible quantity without apparently introducing any disadvantages"—such as loss of engine power, excessive oil consumption, excessive wear and detonation.

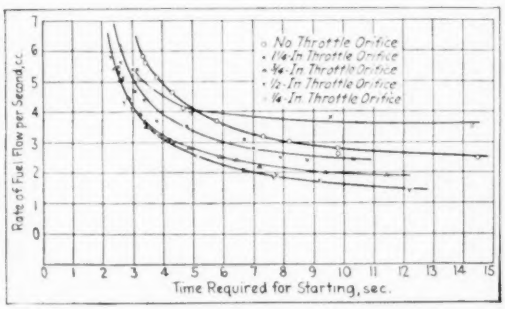


Fig. 11.—(Fig. 14, Engine Starting tests). These curves show the extent of which more complete vaporization and quicker starting is attained by reduction in pressures. Thus a decrease in throttle opening results in a lower pressure in the manifold, while choking reduces the pressure throughout the intake system.

On the other hand, he—"Stresses the fact that the elimination of dilution will inevitably produce lubrication troubles due to the higher viscosity of oil which will prevail, and suggests various methods by which oiling systems may be modified so as to approach more nearly to the ideal condition."

In the carrying out of experiments to develop these facts a dynamometer set-up was used, the engine first being water cooled in the standard way and then subjected to steam cooling, according to the principle developed by S. W. Rushmore, in order to obtain higher and more uniform cylinder temperatures. The results indicate that dilution practically stops when the jacket temperature is between 210 and 220° F.

Effect of Throttling

Dilution, of course, will also vary with the extent of throttling. In other words, under conditions of low throttle operation dilution is generally expected to be greater than under higher power operation. Of course, the matter of vaporization enters into the question especially in regard to the theory concerning the occurrence of dilution by fuel deposition from the vapor state. In this connection the observations, of Eisinger relative to vaporization, pressure and temperature, as brought out by his engine starting tests, are of decided interest.

He states that—"Vaporization is, of course, dependent upon pressure as well as upon temperature. A decrease in throttle opening results in a lower pressure in the manifold. "Choking," that is to say, reducing the opening at the entrance to the carburetor, reduces the pressure throughout the intake system. More complete vaporization and quicker starting would be expected from such reduction in pressure and Figs. 11 and 12 show the extent to which it is obtained. The result of using the 1/4 inch orifice as a throttle appears to be exceptional but is due to the fact that with such a small orifice the amount of liquid fuel striking the orifice plate and being thrown back was increased. The curves as plotted in these figures are not strictly comparable inasmuch as there is a change in air flow with every change in throttle or choke opening, and hence the same fuel flow does not represent the same mixture ratio. Estimates of air flow indicate, however, that if it had been possible to plot the results against mixture ratio pronounced differences due to differences in vaporization would have been shown. Choking would be expected to give somewhat better results than throttling as it reduces the pressure throughout the intake system instead of in the manifold alone. The curves indicate that such is the case."

Clayden in his work investigated this possibility in variation in the rate of occurrence of dilution, making a check run with the engine idling at 250 r. p. m., the lowest possible idling speed attainable. With the jacket temperature maintained at 212° F. he found that the amount of dilution was approximately double that as found under two-thirds full power

operation. This may be due to the fact that under idling conditions cylinder wall temperatures will be lower than when the engine is carrying a load, even though the temperature of the jacket remains approximately the same. As a result condensation or deposition of the vaporous heavy fuel ends could be expected to be greater. His notes in this respect and his general remarks concerning dilution are decidedly pertinent, i. e.:

"It is perhaps interesting to note that the actual dilution shown by 7 hr. idling with the oil at 90° was only 3 per cent. Another point worth while noting is that piston head temperatures apparently have very little to do with dilution except by the indirect method of oil temperature, which is dependent more upon piston head temperatures than upon the temperature of any other part of the engine."

"It may logically be asked, if dilution is controlled principally by cylinder wall temperature, why should the temperature of the oil exercise any influence. Undoubtedly some dilution is due to direct leakage past the pistons during the compression and firing strokes. Such leakage is probably reduced by high cylinder temperature, but not entirely prevented. The amount of any fuel vapors which actually reach the crankcase, that will condense in the oil, will be controlled mainly by the temperature of the oil."

"It is desired to eliminate dilution in order that the viscosity of the lubricant be maintained and there is no place more important for its maintenance than that of the cylinder walls, therefore, if dilution is overcome by removing it *after* it has taken place, then dilution of the working oil film *in the cylinder* has not been affected. By restraining the deposition of gasoline, in other words, preventing the disease instead of curing it, we can be assured of plenty of viscosity in the cylinder."

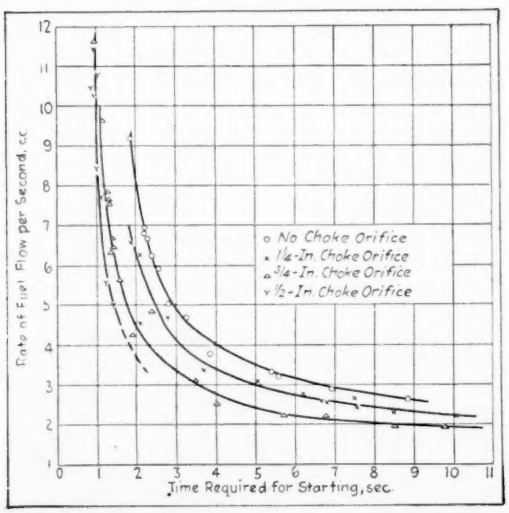

Rate of Fuel Flow per Second, cc
Time Required for Starting, sec.
o No Choke Orifice
× 1/4-In. Choke Orifice
△ 3/4-In. Choke Orifice
▽ 1/2-In. Choke Orifice

Fig. 12.—(Fig. 15, Engine Starting tests.) Curves showing the direct effect of choking upon starting as mentioned in connection with Figure 11. The author states that choking would be expected to give somewhat better results than throttling as it reduces the pressure throughout the intake system instead of in the manifold alone; this is indicated by the curves.

"In other words, a diluent eliminating device can insure viscosity of the oil fed to the bearings, but exercises no control upon the viscosity of the lubricant in the cylinders. On the other hand, the maintenance of high cylinder wall temperature actually prevents the occurrence of dilution and therefore protects both cylinders and bearings.

"At the present time it is not an overstatement to say that nearly all automobiles used in extremely cold weather are protected by dilution. If dilution is really eliminated without any modification of the lubrication system a very epidemic of mechanical failure will come with the first winter. Of course, this condition can be overcome by the use of a lubricant for winter work so light that its viscosity is the same as the present oils have with the normal amount of dilution, but assuming that the object of eliminating dilution is to maintain viscosity, then changing to lighter lubricant would be utterly ridiculous. The fact is that the conventional lubricating systems are faulty, fundamentally, in that they only function properly over too narrow a temperature range. What the pistons and cylinders and the bearings require is a constant volume of oil per revolution, irrespective of viscosity."

Carbon Formation

In connection with this matter of dilution it is decidedly necessary to keep in mind the relation which it bears to excessive carbon formation, or the building up of so-called carbon deposits, not only on spark plugs, pistons, cylinder heads, around the rings, and on the valves and seats, but also in the crankcase or oil sump itself.

While carbon formation is more generally attributed to incomplete combustion of the fuel, to the use of excess lubricating oil or to the entry of silicious foreign matter such as road dust via the air intake or breather pipe, we must not lose sight of the fact that dilution is also a pertinent contributor. In other words, it is perfectly evident that the lighter the lubricant or the thinner the film on the cylinder walls, the more readily will it splash or succumb to the wiping effects of the piston. This will of course increase the possibility of pumping or forcing of the lubricating film up into the combustion chamber where it will be ultimately burned. The direct result is the development of more or less carbon deposits therein.

The intensity of these latter will, of course, depend upon the residual carbon content of the oil. Where the latter burns cleanly the amount of such deposits will be relatively small. Furthermore, if the oil is properly refined and adapted to the purpose such carbonaceous matter will be soft in appearance, low in quantity and comparatively easy of removal.

Over extended periods of operation, however, carbon deposits whatever their nature will be bound to increase. Furthermore, where pumping or forcing of a certain amount of lubricating oil into the combustion chamber occurs, the ultimate oil consumption will be higher, with a reduction in the mileage developed per gallon. In addition, dilution may involve the possibility of a certain amount of loss of compression due to impairment of the piston seal when the viscosity of the oil is so reduced that the lubricating film is comparatively readily wiped off by the piston rings.

So it is important to operate an engine at all times with a view to reducing the occurrence of crankcase dilution as much as possible. To bring this about and promote the efficiency of operation, and extend the life of the engine bearings and cylinders, certain precautions must be observed. In brief, they are:

1. Run on as lean a mixture as possible in conformation with atmospheric temperature and the load to be handled.
2. Do not flood the carburetor.
3. Prime as little as possible.
4. In cold weather be sure that the hot air intake pipe attachment is in proper position to enable the admission of heated air to the carburetor.
5. Keep the engine warm, especially in cold weather.
6. When necessary to use the choke, let the sound of the engine be the guide. As soon as one or two revolutions are made and the engine indicates steady running, push the choke back in or turn the handle to "hot" position according to the make of the car.
7. Never flush the crankcase with kerosene alone except where arrangement of the oiling system permits complete drainage of the case. Always give it a final slushing with light motor oil. Kerosene is helpful in removing heavier particles of adhesive sludge.
8. Change the oil at frequent intervals. The cost of oil is negligible in comparison with the cost of lay-up and repairs on the average commercial vehicle.

Other Causes of Carbon

The various other causes of carbon formations also require attention. Of these incomplete combustion can be regarded as the more usual. In general it will be the result of carelessness or ignorance in regard to carburetor adjustments, the resultant mixture of gasoline and air being unsuited to the power requirements and engine conditions involved. Carburetors, of course, should not be tampered with too frequently, nor by inexperienced employes. They should, however, receive attention commensurate with atmospheric temperature conditions. Normally they are adjusted when hot in order to obtain the best fuel economy, and to decrease dilution as much as possible.

The use of too much lubricating oil is another frequent reason for abnormal carbon deposits. Theoretically a very small amount of oil is necessary to maintain the requisite lubricating film on the cylinder walls and serve the respective bearings; actually, however, a considerable excess of oil will be used. Provided the rings give the proper degree of seal and the cylinder walls are not abnormally worn, but little of this oil should pass to the combustion chamber. If the oil level is carried too high, however, especially in oiling systems involving splash lubrication, the amount of oil on the cylinder walls may be so excessive that a certain percentage cannot help but find its way into the combustion chamber. Either burning oil or incomplete combustion will be indicated by the smoky appearance of the exhaust.

A certain amount of free carbon will also be present in practically every crankcase after the lubricant has been in service a short time. In part this is caused by breaking down or partial decomposition of the lubricating oil; and in part, as stated, to incomplete combustion of the fuel. Subsequently certain of the resultant carbon of fluffy or pulverized nature is carried into the crankcase by the diluent portions of the fuel, or the lubricating film on the cylinder walls. Carbon in the crankcase is detrimental in that it not only promotes the formation of crankcase sludge, but as well is influential in producing emulsions.

Dirt, grit and road dust comprise the final more usual cause of carbon formations. Foreign matter of this nature is perhaps the most detrimental to any engine. Not only does it tend to become a part of any real carbon deposit above the piston, but also when present in the lubricating system there will always be a possibility of the bearings being scored.

Dirt, grit and other abrasive particles may find their way into the lubricating system in a number of ways. The oil may originally have contained such foreign matter if it has not been carefully refined; the oil storage or measuring containers may have been dirty;

the operator may have neglected to replace the cap on the filling pipe, or have accidentally brushed some dirt from the hood or engine into this pipe or his filling measure; or road dust, etc., may have been taken into the engine with the air, either by way of the carburetor or the crankcase breather device.

Just as long as the lubricating film is sufficiently thick to prevent any such foreign matter from coming simultaneously into actual contact with both bearing surfaces, little or no damage will result, and the possibility of scoring will be negligible. But as soon as the viscosity of the lubricant becomes so lowered by dilution that the film thickness is materially decreased, it will no longer serve as a carrying medium for abrasive foreign matter. In other words, such particles of grit, dust or dirt as may gain entry to the bearings will be carried through them in actual contact between the wearing surfaces, and scoring will be bound to occur.

CHANGING OILS:

As a result of the above investigations and the data developed, more emphasis than ever should be laid upon the matter of draining the crankcase and renewing motor oils, in order to minimize the effects of contamination. The frequency of draining will, of course, depend to some extent upon the operating conditions to which the car is subjected, the grade of fuel, and the season of the year.

Crankcase draining should be carried out just after a run and while the engine is still hot. A considerable percentage of the contained solid impurities and sludge will thus have become churned up in the oil and can so be readily removed with the oil, obviating the necessity of flushing the case to any great extent. One or possibly two flushings with about a quart of warm light motor oil, however, will never be amiss and is always an insurance that dirt and sludge have been removed from certain corners and crevices in the engine when the oil does not circulate freely.

Kerosene alone as an engine wash is not recommended due to the possibility of a certain amount of it remaining in parts of the case which are set at a lower level than the drain plug, and thus being the subsequent cause of a certain amount of dilution. When the engine is flushed it should be turned over slowly either by hand or with the starter. It is bad practice to run it under its own power, inasmuch as there will be danger of lack of lubrication and therefore damage to the bearings.

Where the car is new and the engine must be broken in, or where the cylinders have been recently re-bored, the metallic bearing surfaces will have a tendency to wear down or become polished. The result of this is the separation of minute particles of metal which will constitute part of the sludge. Usually this will take place until bearing and cylinder walls have been worked down to a "running fit." Such a fit will be obtained after approximately 1000 miles of service. Therefore, it is advisable to change the motor oil more frequently over this period of operation. If the crankcase is drained and flushed in the usual manner after each 200 to 300 miles of operation, four of such changes should suffice to remove excessive abrasive and metallic material and insure against the occurrence of any abnormal wear of bearings, piston rings, or cylinder walls, etc., or the possibility of clogged oil ducts or pump screen.

CONCLUSION:

If these precautions are observed and more heed given to the findings of science better operation of *your* car or truck will be bound to result.

The automotive engineer today is a practical scientist. His laboratory and *your car* are his workshops. Therefore the fruits of his labor should be indicated (with your cooperation) by the functioning of your engine.

Printed in U. S. A. by
EDGAR C. RUWE CO., INC.
47 West Street, N. Y. C.